The New L2 Civil Signal

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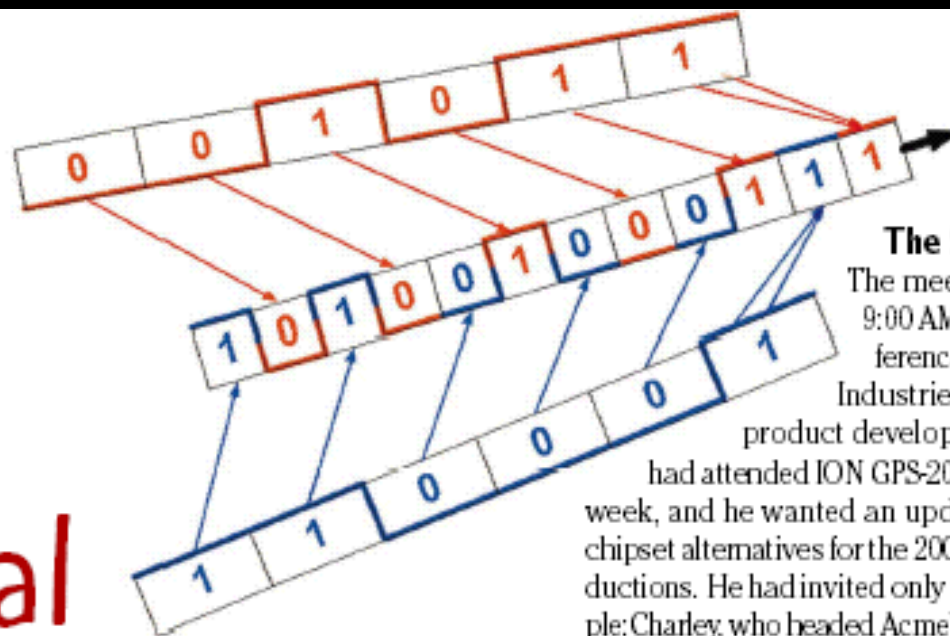
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SYSTEM

Challenge

The Modernized L2 Civil Signal

Leaping Forward in the 21st Century

by Richard D. Fontana, Wai Cheung, and Tom Stansell

The Scene: 2008

The meeting started at 9:00 AM in a small conference room at Acme Industries. Fred, Acme's product development manager, had attended ION GPS-2008 the previous week, and he wanted an update on the GPS chipset alternatives for the 2009 product introductions. He had invited only three other people: Charley, who headed Acme's dual-frequency and high precision GPS product developments, Valerie, who headed GPS-based consumer product developments, and Albert, from marketing.

Under Fred's direction, Acme offered a wide array of GPS and non-GPS products for both the professional and consumer markets. Years ago Acme had recognized how important GPS was for many applications, so it acquired a few small companies with expertise in designing and applying positioning technology. By 2008, Acme had become a major supplier of GPS-based equipment for high precision, OEM, and consumer applications, although it had not entered the aviation or military markets.

This article reveals . . .

■ how the new L2 signal, scheduled to originate from GPS satellites in space from 2003 onwards, will affect both

A funny thing happened on the road to GPS modernization: a signal suddenly changed. After years of preparation, modernization called for:

⊕ implementing military (M) code on the L1 and L2 frequencies for the Department of

Topics

- Acknowledgements
- Development framework
- Signal description
- Acquisition and code tracking
- Message options
- Relative signal performance
- Future choice of signals
- Signal characteristics summary
- L2C advantages

Special Acknowledgements

- Col. Douglas Loverro – why replicate C/A code?
- Steve Lazar – first analysis and R/C code option
- LCDR Richard Fontana – led & coordinated JPO effort
- Wai Cheung – organized, hosted, managed
- Dr. Charlie Cahn – codes, analyses, insight & wisdom
- Dr. Phil Dafesh – lower bit rate & hardware demo
- Rich Keegan – validated receiver feasibility
- Tom Stansell – coherent carrier, guided, presented
- Dr. A.J. Van Dierendonck – alternatives, L5 experience
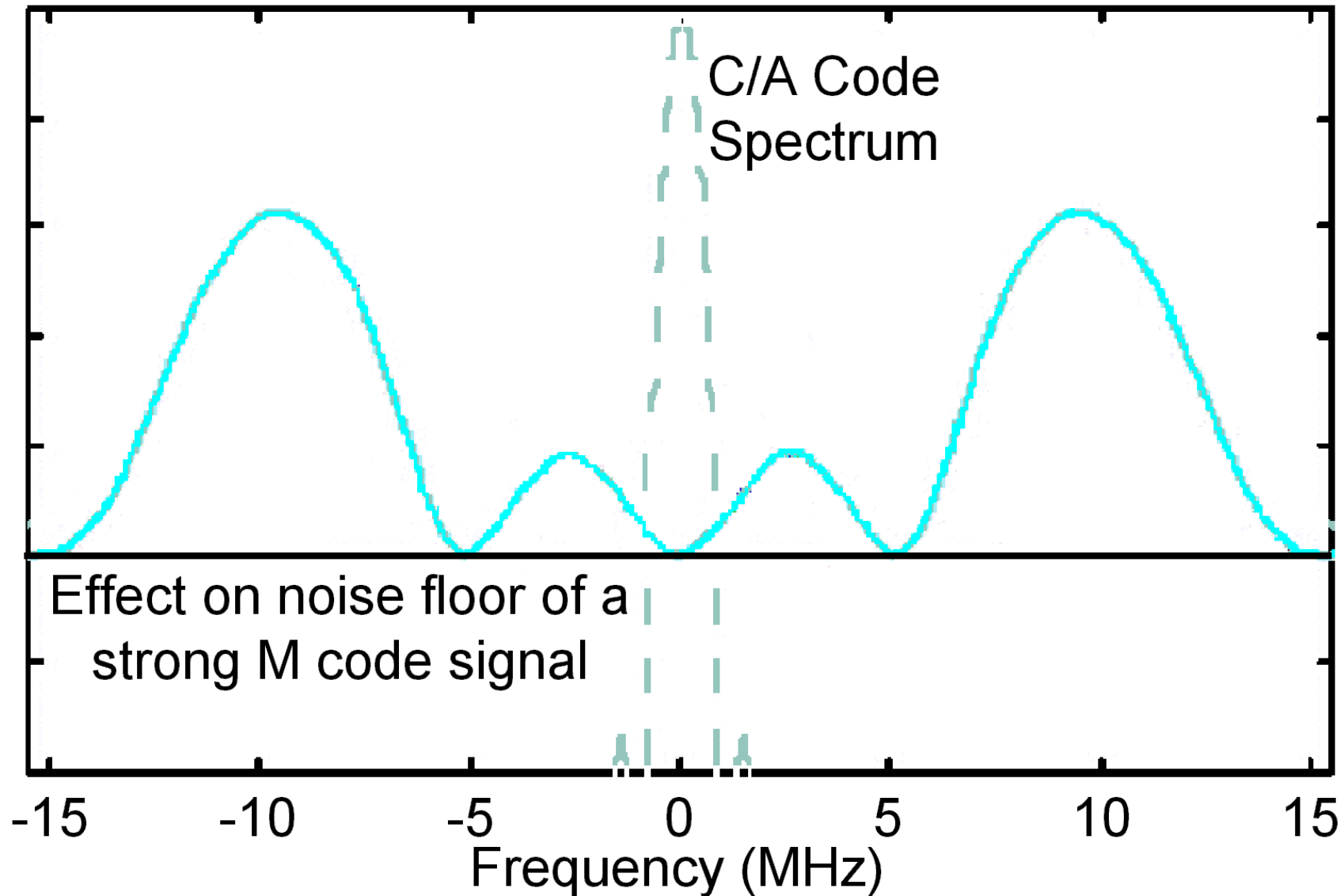- Karl Kovach, Soon Yi, Dr. Rhonda Slattery – document

Development Framework

- ◆ **Tight schedule (1.5 months, 3 meetings)**
- ◆ **Limited chip rate (spectral separation)**
- ◆ Bi-phase signal at lower power (shared with P/Y)
- ◆ Application requirements
- ◆ Modern technology (to acquire longer codes)
- ◆ Dramatic increase in new GPS signals

Spectral Separation Limits Civil Chip Rate

C/A Code Spectrum

Effect on noise floor of a strong M code signal
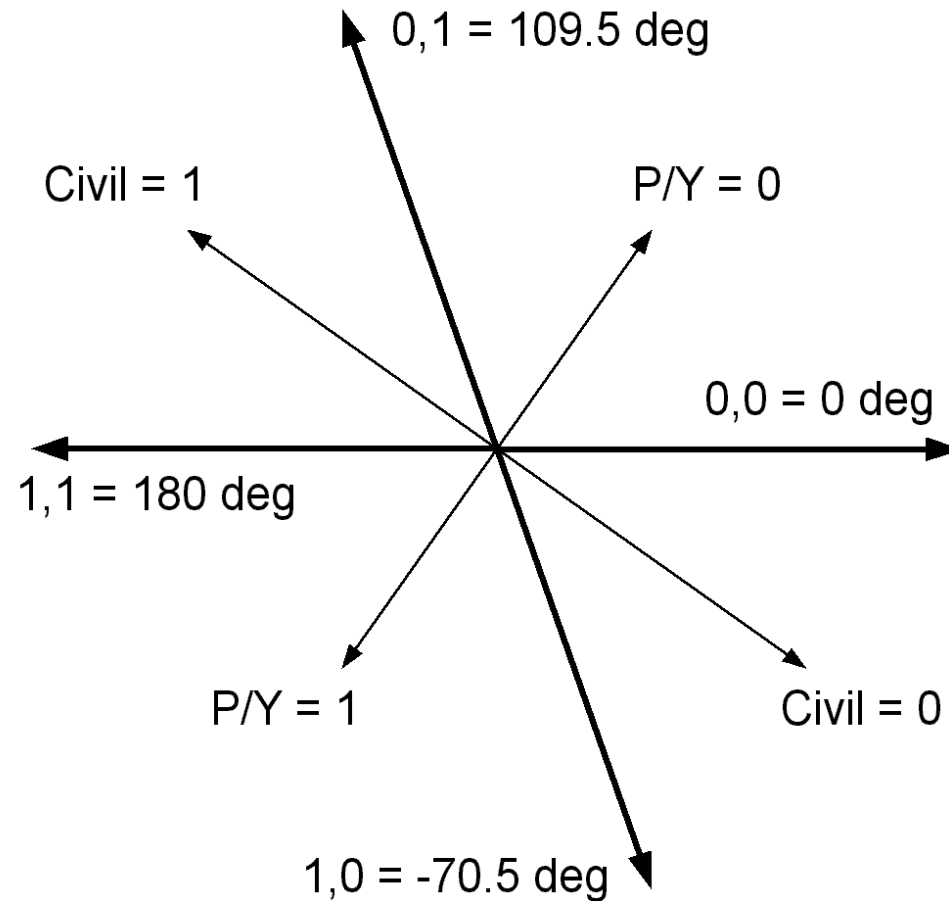
Frequency (MHz)

Development Framework

- ◆ Tight schedule (1.5 months, 3 meetings)
- ◆ Limited chip rate (spectral separation)
- ◆ **Bi-phase signal at lower power**
    - **L2 civil signal is shared with the military P/Y code**
    - **L5 has 2 bi-phase components in phase quadrature**
    - **L2 civil power is ~ 2.3 dB less than L1 C/A**
- ◆ Application requirements
- ◆ Modern technology (to acquire longer codes)
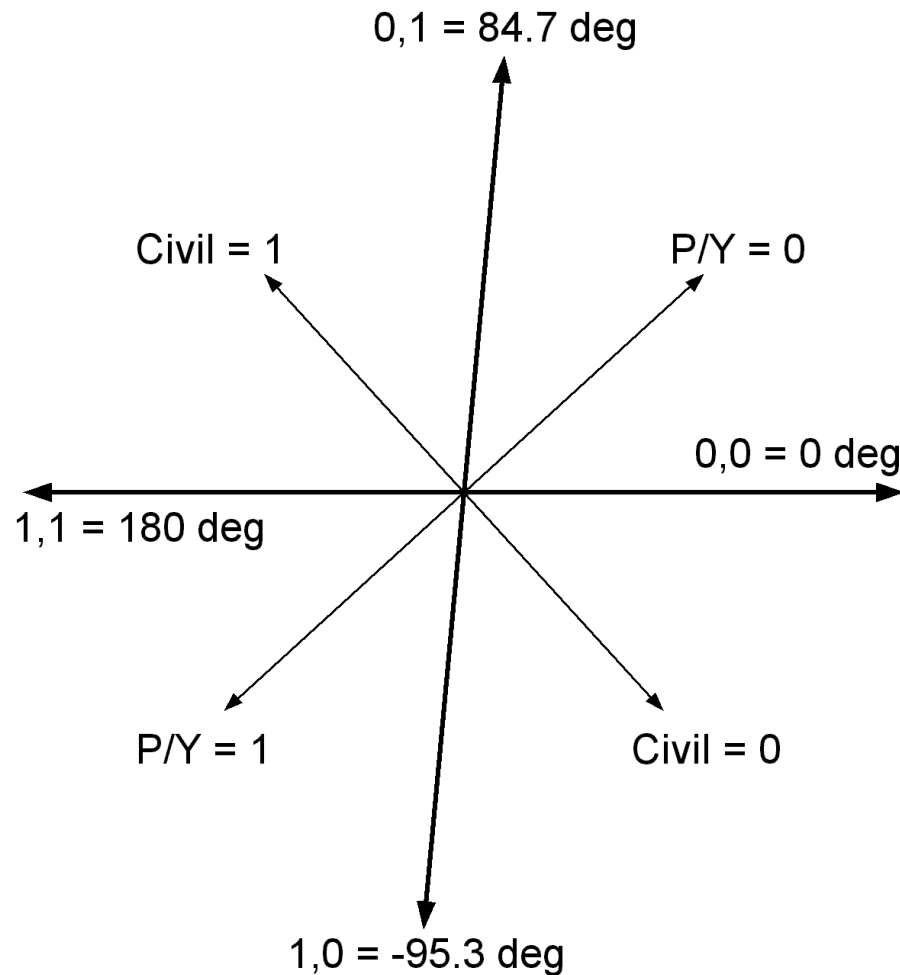- ◆ Dramatic increase in new GPS signals

L1 Signal Component Vector Relationships

0,1 = 109.5 deg

Civil = 1

P/Y = 0

0,0 = 0 deg

1,1 = 180 deg

P/Y = 1

Civil = 0

1,0 = -70.5 deg

**L1 Phase Relationships
(Civil is 3 dB stronger than P/Y)**

L2 Signal Component Vector Relationships

0,1 = 84.7 deg

Civil = 1

P/Y = 0

0,0 = 0 deg

1,1 = 180 deg

P/Y = 1

Civil = 0

L2 Civil is ~2.3 dB weaker than L1 Civil on IIR-M and IIF Satellites

1,0 = -95.3 deg

L2 Phase Relationships
(Civil is 0.4 dB weaker than P/Y)

Development Framework

♦ Tight schedule (1.5 months, 3 meetings)

♦ Limited chip rate (spectral separation)

♦ Bi-phase signal at lower power (shared with P/Y)

♦ **Application requirements**

♦ Modern technology (to acquire longer codes)

♦ Dramatic increase in new GPS signals

Two Primary L2C Application Requirements

♦ **Dual-frequency civil users**

- About 50,000 used for high value applications
  - ➔ Scientific: earthquakes, volcanoes, continental drift, weather
  - ➔ Cadastral and construction land survey
  - ➔ Guidance & control: mining, construction, agriculture
  - ➔ Land and offshore land and mineral exploration
  - ➔ Marine survey and construction
- Need a civil code to replace semi-codeless tracking

♦ **Single frequency with wide dynamic range**

- Avoid crosscorrelation problems of C/A code
- E911 inside buildings, forest areas, tree-lined roads

Dual Frequency Transition Issue

◆ Is L2 phase, measured with a code, the same as a semi-codeless phase measurement?

- Semi-codeless L2 phase is L1 C/A phase plus the phase difference between L2 and L1 P/Y phase

$$L2 = L1_{C/A} + (L2_{P/Y} - L1_{P/Y})$$

- Any difference in the P/Y to C/A quadrature phase relationship between L1 and L2 will cause a bias relative to a code-based phase measurement
  - ➜ Are the differences negligible? For sure?
  - ➜ Can they be calibrated? Are they stable?
  - ➜ How to identify which measurement technique was used?
  - ➜ Should both measurements be made during transition?
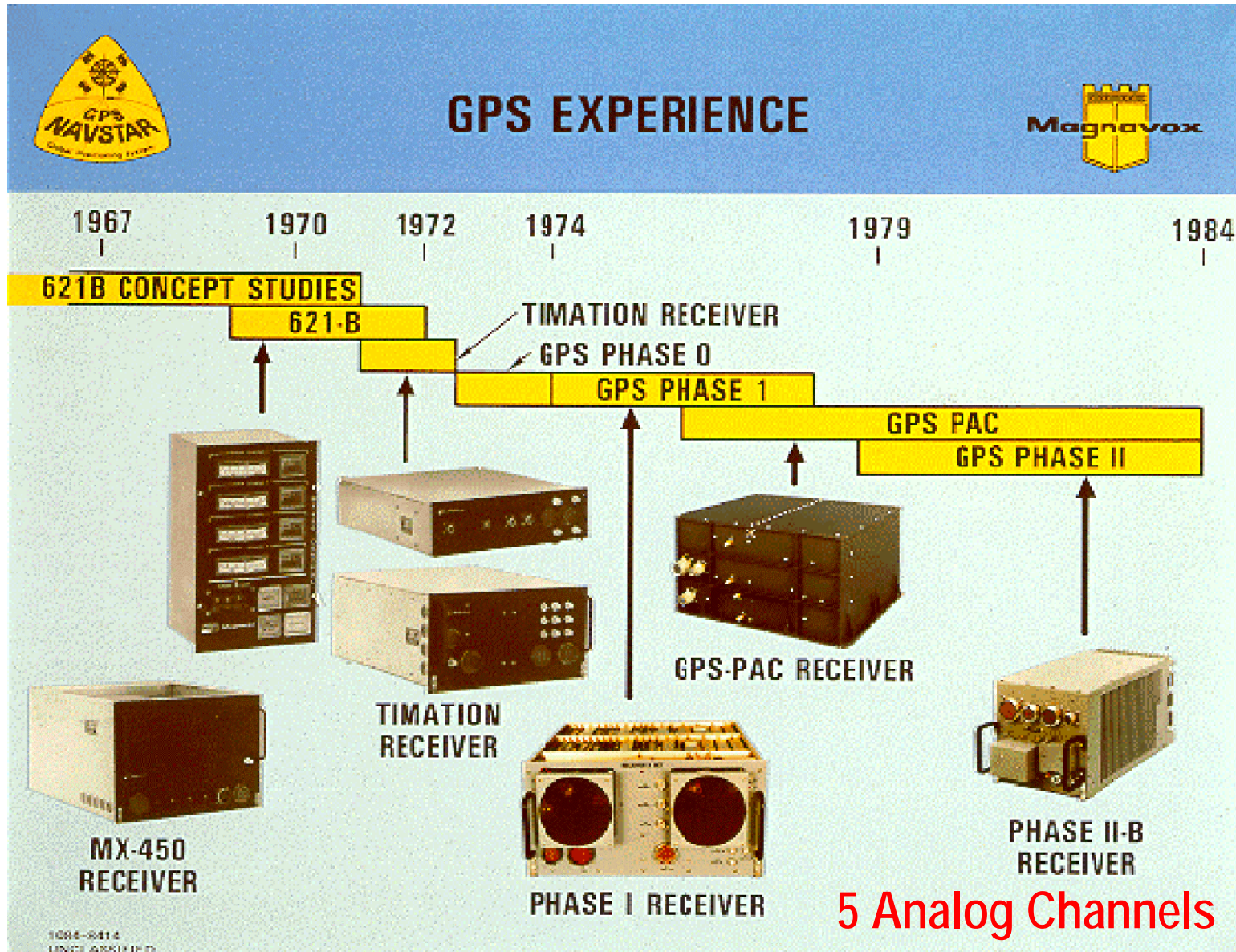
Development Framework

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- ◆ Dramatic increase in new GPS signals

C/A Code Developed for 1970's Technology

5 Analog Channels

Dramatic Technology Progress since the 1970's

Consumer 12 channel with color map

Consumer 12 channel for under $100

Development Framework

- Tight schedule (1.5 months, 3 meetings)
- Limited chip rate (spectral separation)
- Bi-phase signal at lower power (shared with P/Y)
- Application requirements
- Modern technology (to acquire longer codes)
- **Dramatic increase in new GPS signals**

Historic Increase in GPS Navigation Signals

Signal\SV	IIR	IIR-M	IIF
L1 C/A	✔	✔	✔
L1 P/Y	✔	✔	✔
L1 M		✔	✔
L2 Civil		✔	✔
L2 P/Y	✔	✔	✔
L2 M		✔	✔
L5 Civil			✔
	1978 to 2003	**2003**	**2005**

Expected Growth in L2C and L5 Signals

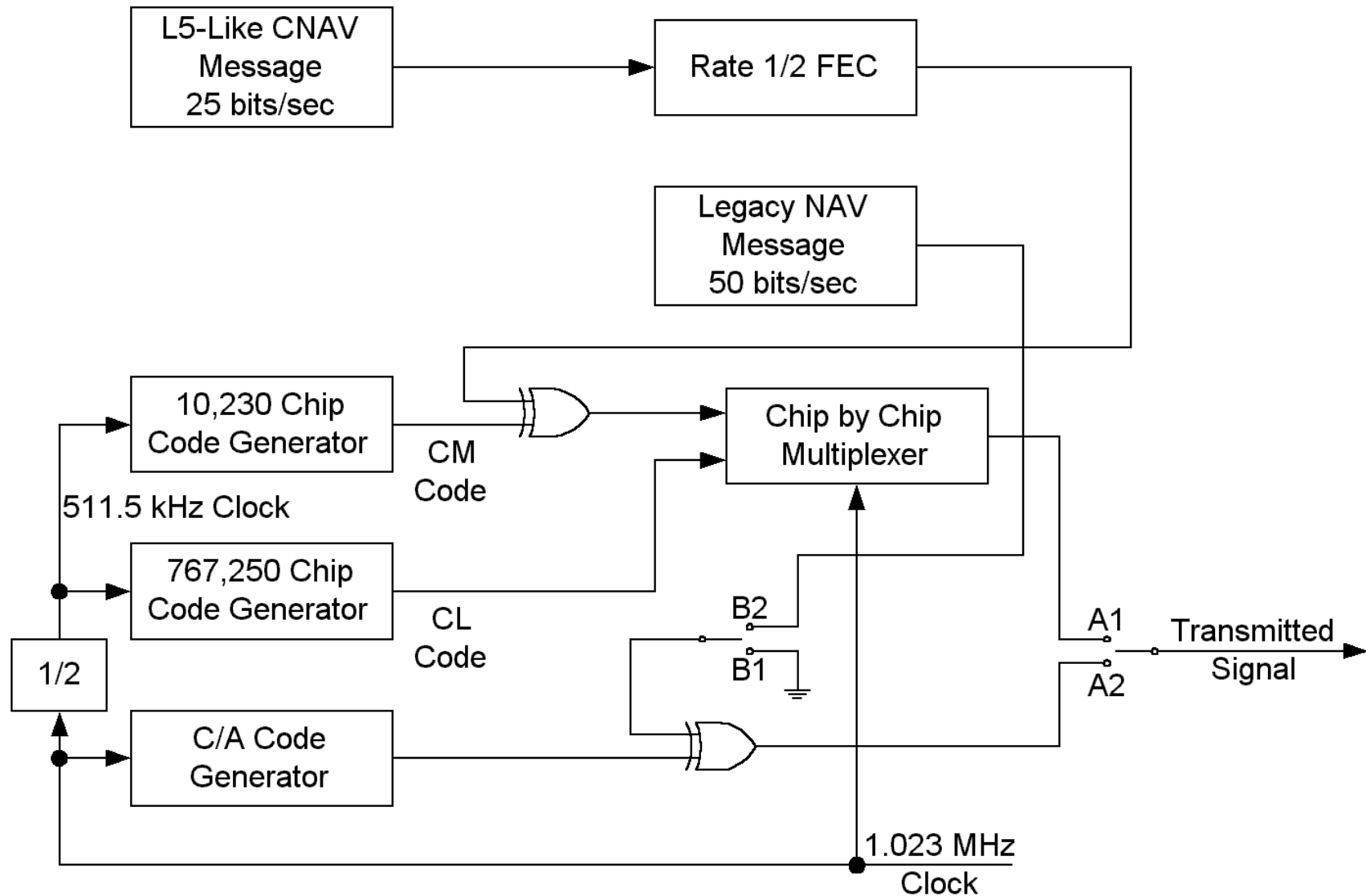Assumes modernization of 12 IIR Satellites
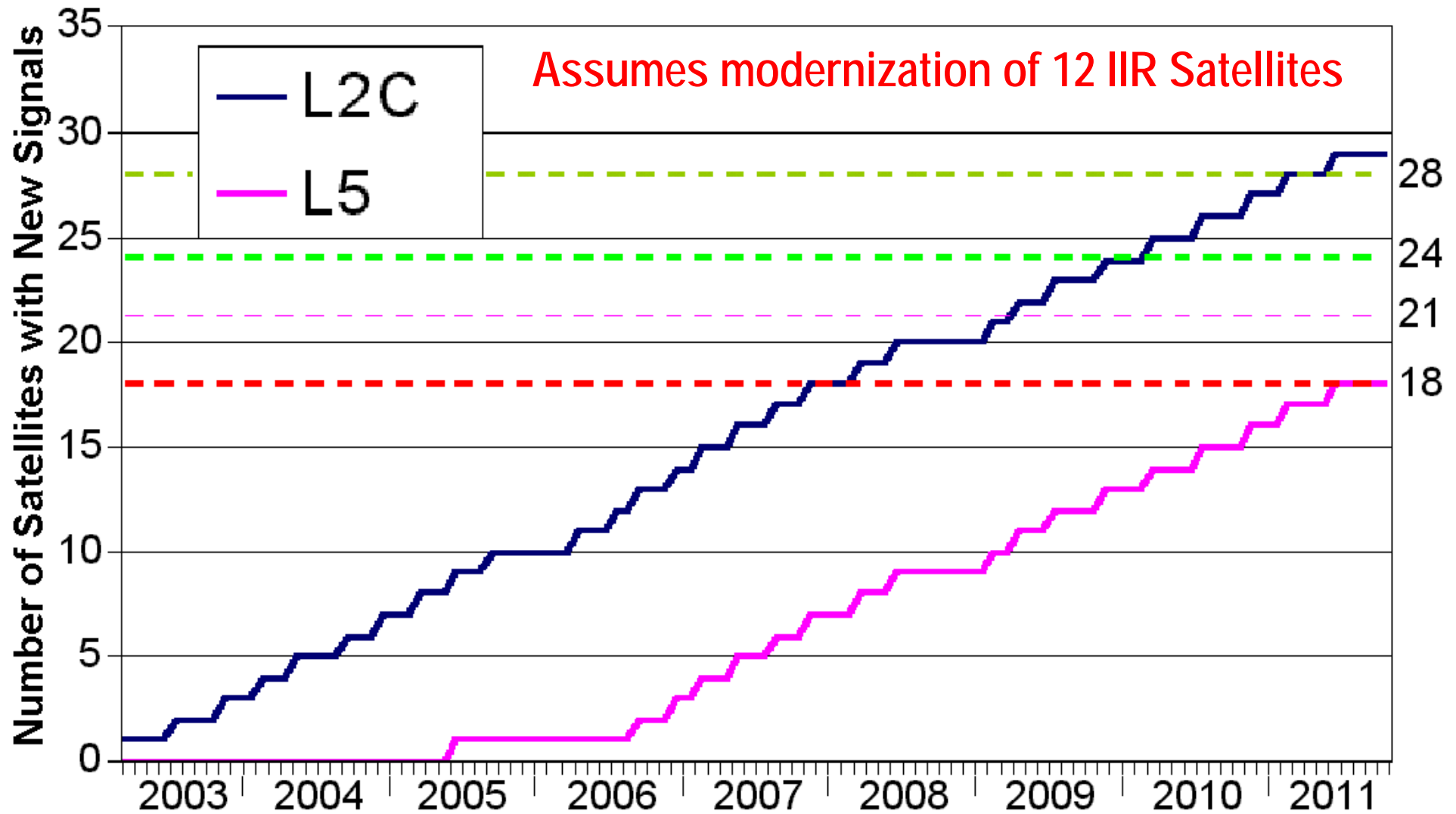
L2C Definitions

- **L2C** – the new L2 Civil Signal
- **CM** – the L2C moderate length code
  - 10,230 chips, 20 milliseconds
- **CL** – the L2CS long code
  - 767,250 chips, 1.5 second
- **NAV** – the legacy navigation message provided by the L1 C/A signal
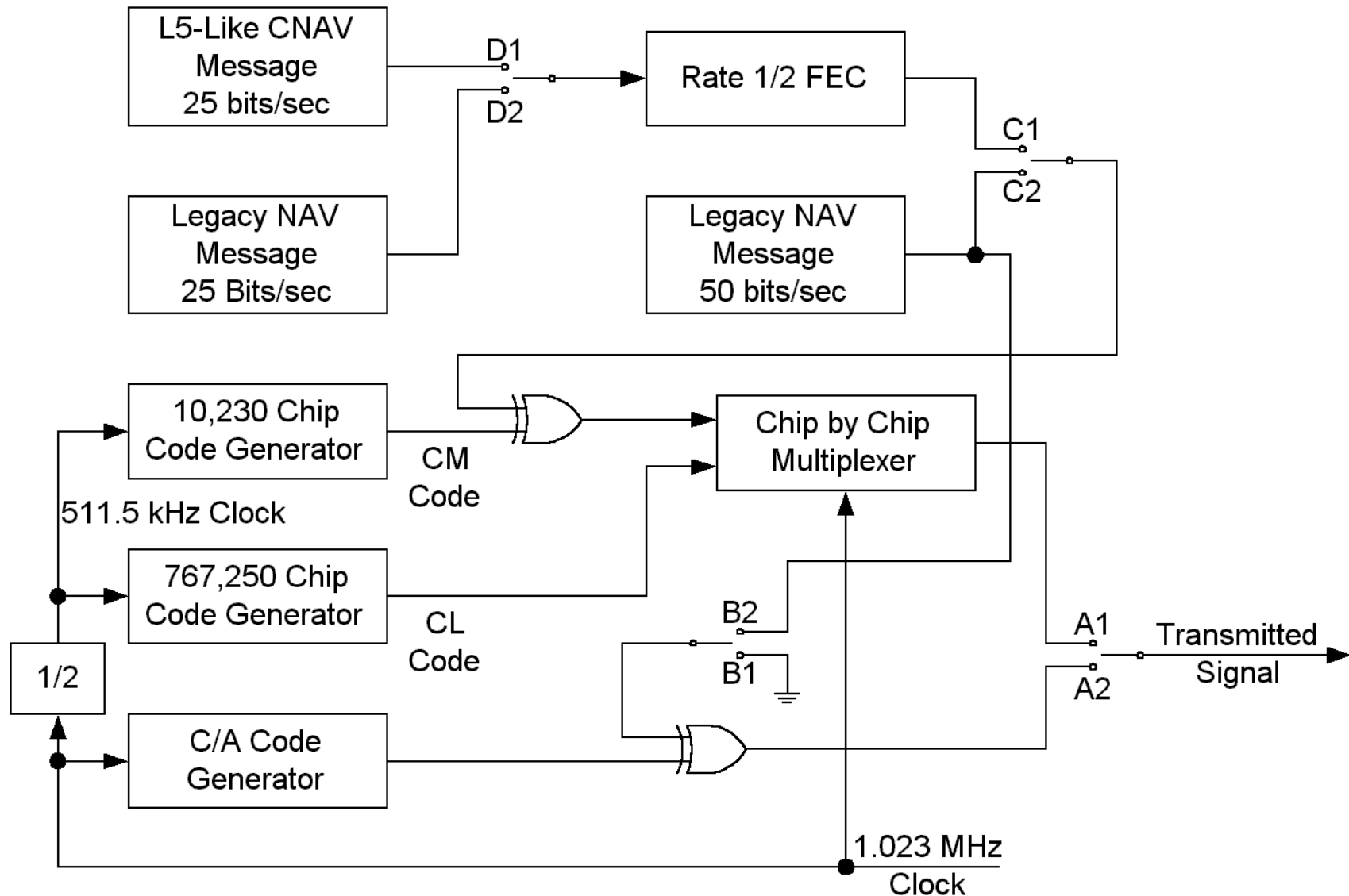- **CNAV** – a navigation message structure like that adopted for the L5 civil signal

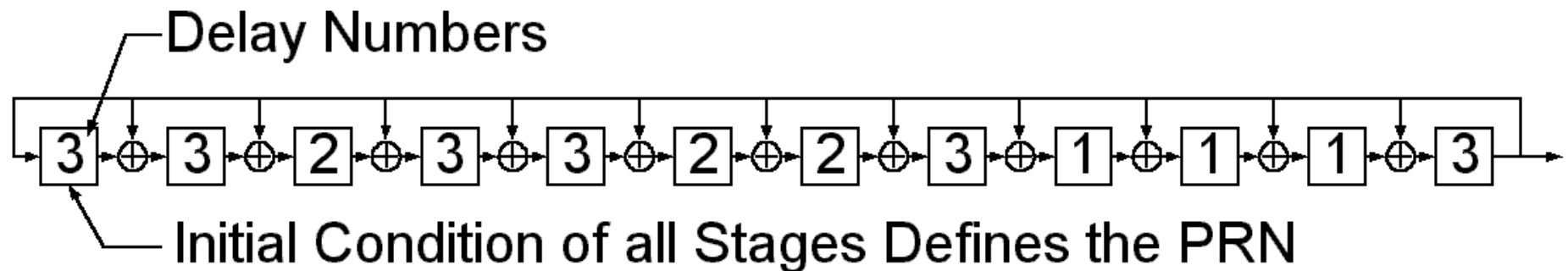# L2C Signal Options on IIF Satellites

L2C Code Generation and Definitions

Delay Numbers

```
┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐⊕┌──┐
│3 │  │3 │  │2 │  │3 │  │3 │  │2 │  │2 │  │3 │  │1 │  │1 │  │1 │  │3 │
└──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘  └──┘
```

Initial Condition of all Stages Defines the PRN

Period=10,230 Chips		
CM Code States (Octal)		
PRN	START	END
1	742417664	552566002
2	756014035	034445034
3	002747144	723443711
4	066265724	511222013
5	601403471	463055213
6	703232733	667044524
7	124510070	652322653
8	617316361	505703344
9	047541621	520302775
10	733031046	244205506

| Period=767,250 Chips		
CL Code States (Octal)		
PRN	START	END
1	624145772	267724236
2	506610362	167516066
3	220360016	771756405
4	710406104	047202624
5	001143345	052770433
6	053023326	761743665
7	652521276	133015726
8	206124777	610611511
9	015563374	352150323
10	561522076	051266046

Signal Acquisition and Code Tracking

◆ Normally acquire L2C using CM code (10,230 chips)
  - CL code is 75 times longer than CM code
  - Employ frequency locked or Costas loop during acquisition
    ➜ CM has data modulation
  - Test the 75 possible phases of CL
  - Acquire CL, track phase with a simple phase locked loop
    ➜ Improves threshold by 6 dB relative to a Costas loop

◆ After the first, it is possible to acquire CL codes directly
  - 19,130 chip search range
  - Allows longer coherent integration time (e.g., FFT with long sample interval)
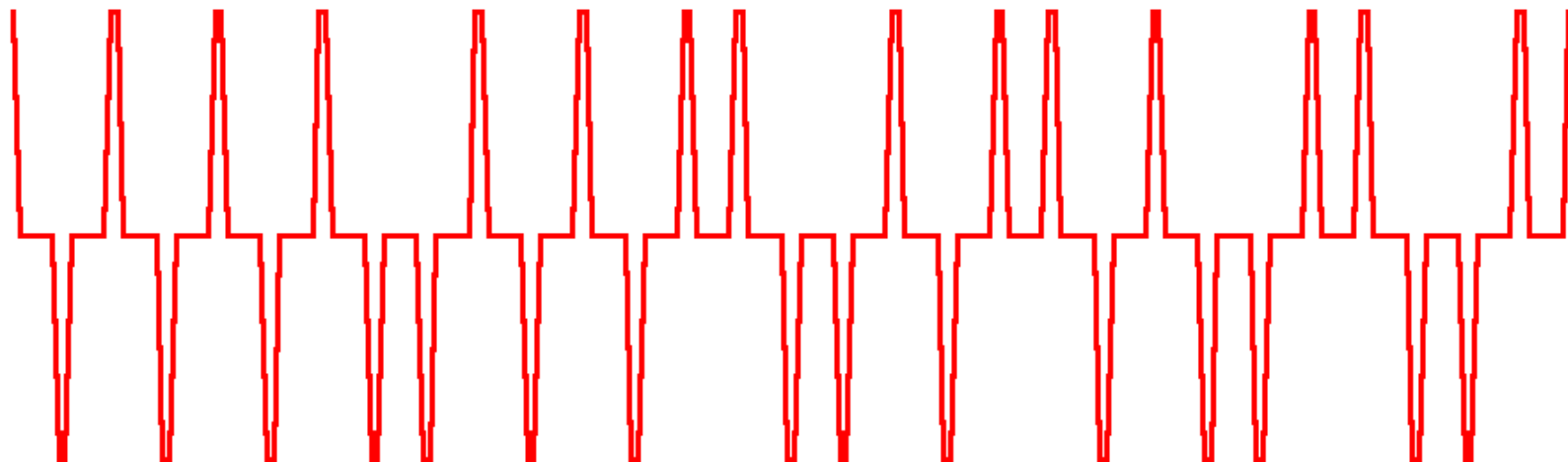
Tracking Continuous Code
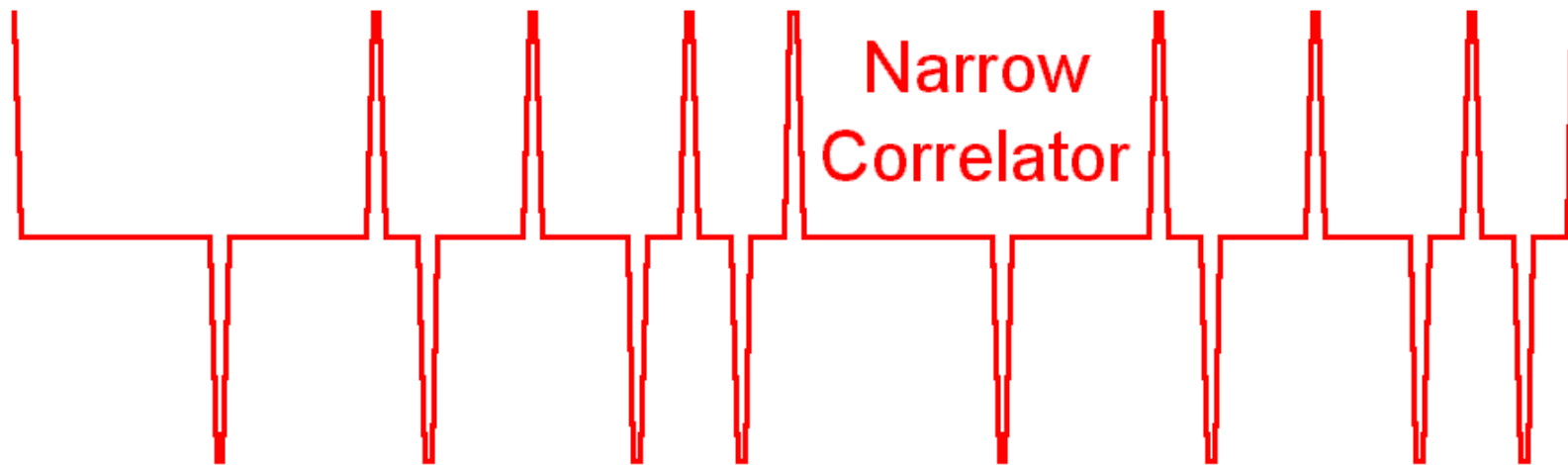
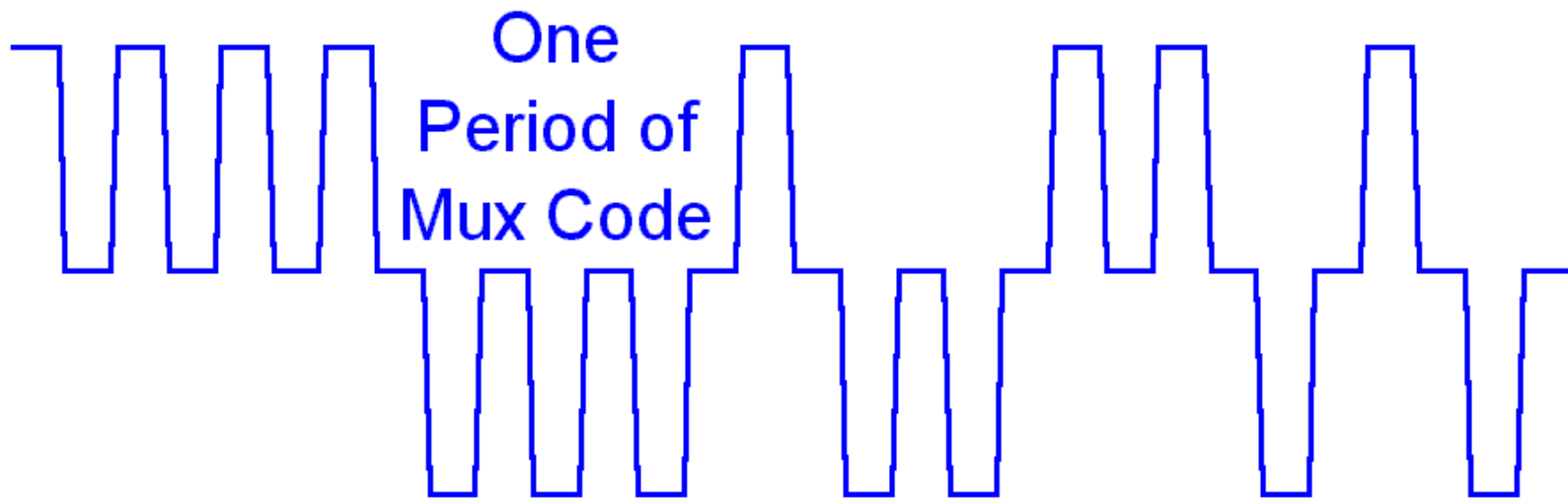Narrow Correlator

Two Periods of Normal Code
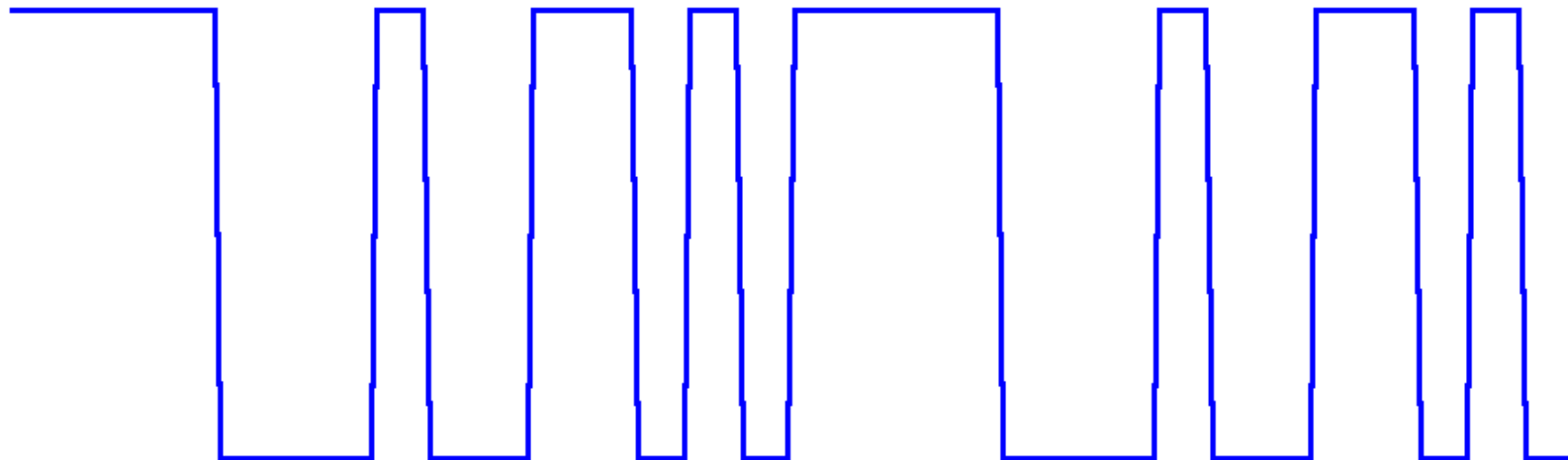
Tracking Chip by Chip Multiplexed Code

Narrow Correlator

One Period of Mux Code

Code Tracking Accuracy

- ◆ Does a lower code clock rate hurt navigation accuracy?
  - Doesn't higher clock improve loop S/N and reduce multipath ?
  - Two factors eliminate this concern
- ◆ High S/N in very narrow bandwidth code tracking loop
  - Carrier aided code loops see only ionospheric dynamics
  - Code loop bandwidth of 0.1 Hz entirely adequate
  - Carrier aided code smoothing ➔ 0.008 to 0.003 Hz BW
  - Zero baseline tests show centimeter level code noise
  - High accuracy does not require better loop S/N
- ◆ Multipath mitigation correlator achieves the <u>same</u> multipath performance of a higher clock rate

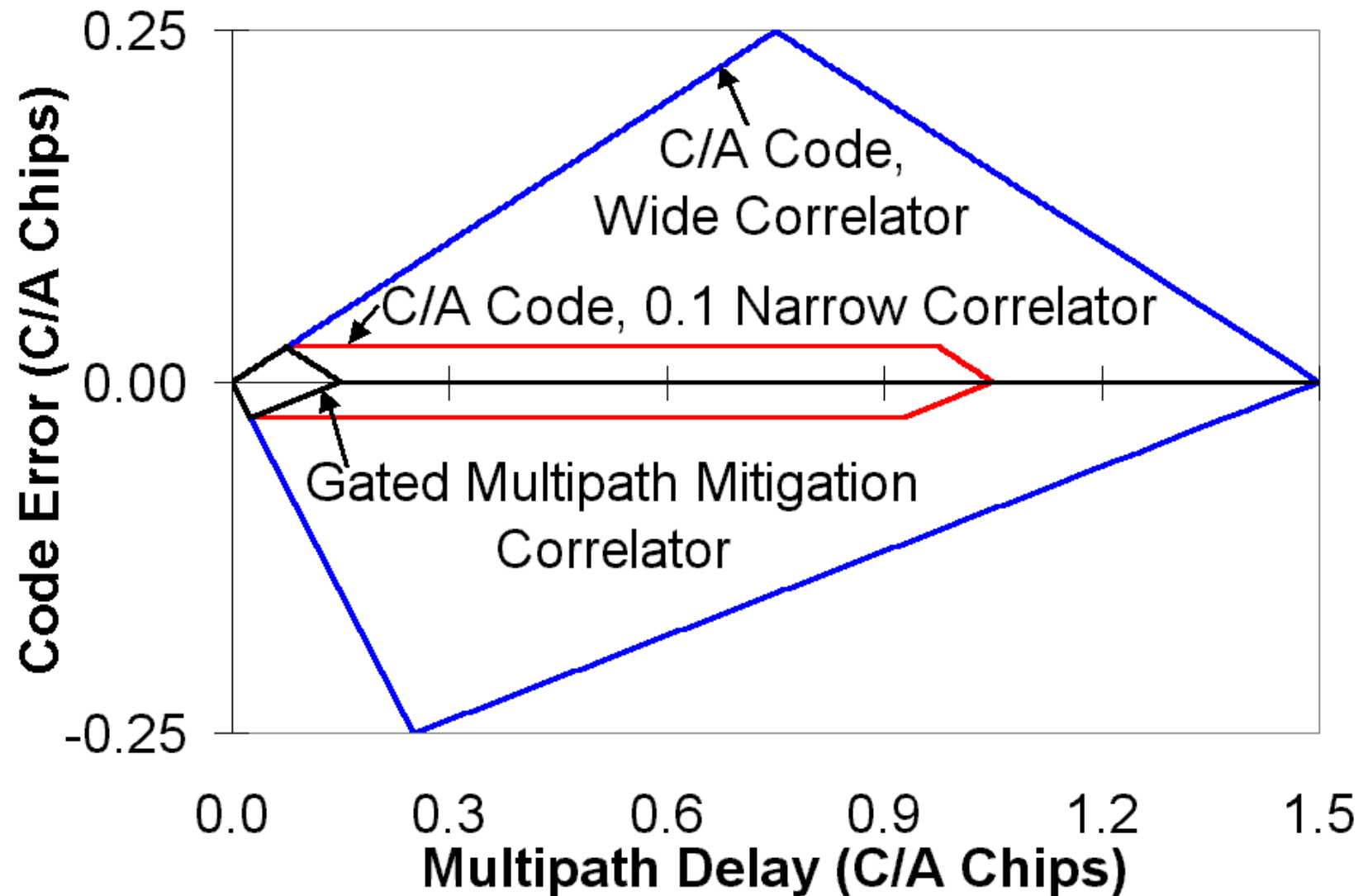# Multipath Error for Three Correlator Types
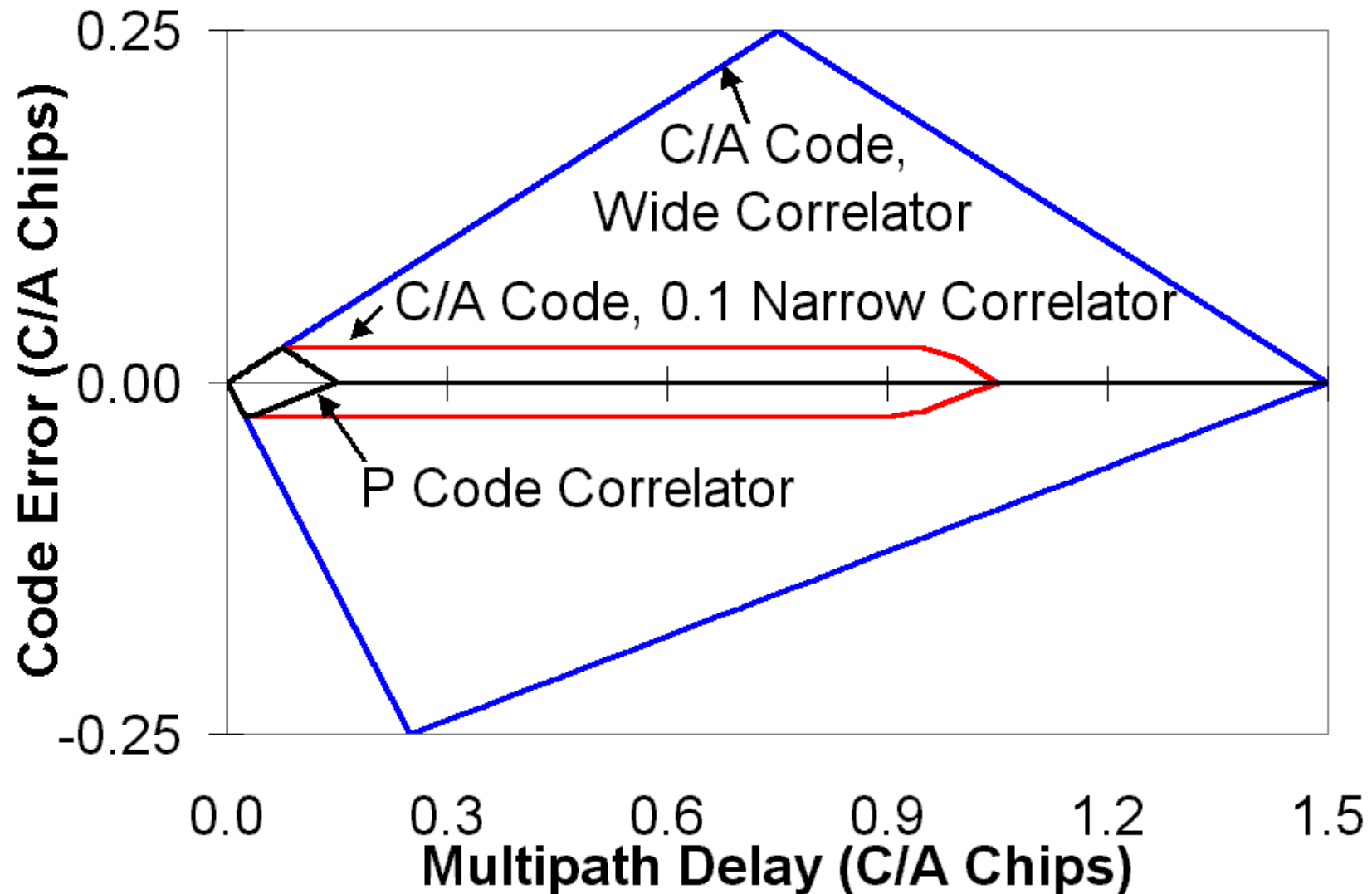
Two L2C Message Frame Alternatives

Type 1
Type 2
Other Type

36 sec frame
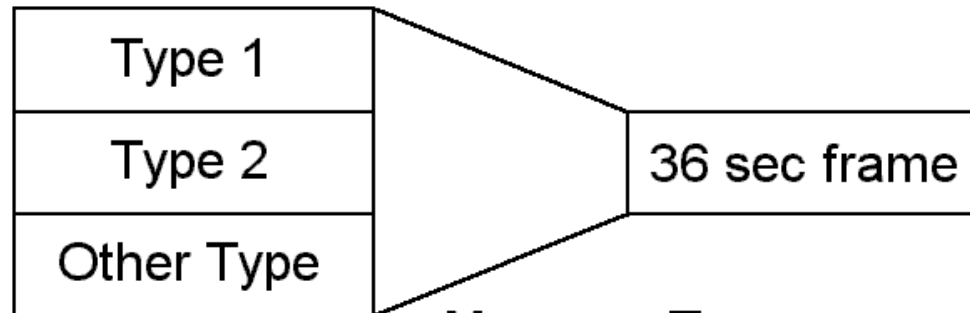
Message Types
1 = Ephemeris A
2 = Ephemeris B
3 = Iono, Bias, Health
4 = Almanac
5 = Text

Type 1
Type 2
Other A
Other B

48 sec frame
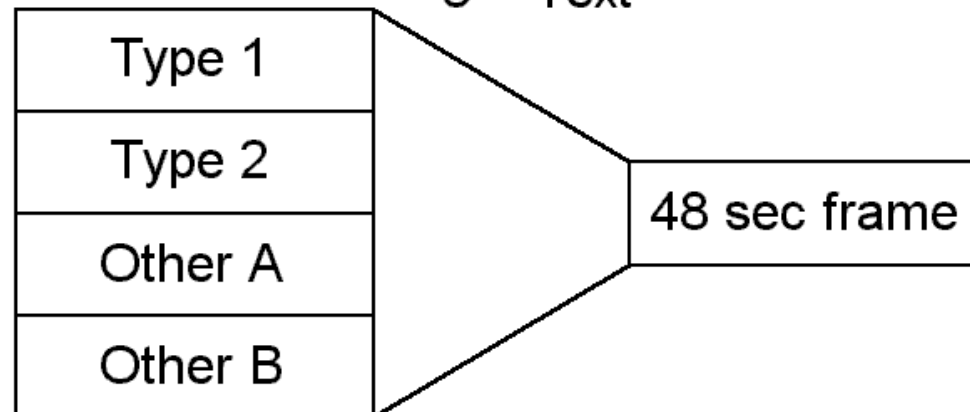
Potential Message Improvements

◆ Almanac with 7 orbits in one subframe

◆ New ephemeris message

- One rather than two subframes
- Better accuracy
- Longer validity

◆ Both significantly benefit L2C performance because of its 25 bps message rate

L2C vs. C/A on L2

	Relative Data Channel Power	**Relative** Data-Less Channel Power
L2 C/A	0.0 dB	None (Costas)
L2C	-3 dB	-3 dB

	Relative Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L2 C/A	0.0 dB	0.0 dB
L2C	+5.0 dB (FEC = 5 dB) (25 bps = 3 dB)	+3 dB (Phase locked tracking = 6 dB)

L1 C/A vs. L2C vs. L5 with IIR-M and IIF Satellites

	Received Power	**Relative** Total Power
L1 C/A	-157.7 dBW	0.0 dB
L2C	-160.0 dBW	-2.3 dB
L5	-154 dBW	+3.7 dB

	Relative Data Channel Power	**Relative** Data-Less Channel Power
L1 C/A	0.0 dB	None (Costas)
L2C	-5.3 dB	-5.3 dB
L5	+0.7 dB	+0.7 dB

Relative Data and Carrier Tracking Performance

	Relative Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L1 C/A	0.0 dB	0.0 dB
L2C	+2.7 dB (FEC = 5 dB) (25 bps = 3 dB)	+0.7 dB (Phase locked tracking = 6 dB)
L5	+5.7 dB (FEC = 5 dB)	+6.7 dB

Balanced Data & Carrier Tracking Thresholds

Data rate (bps) & FEC rate	Carrier power percent	WER = 0.015 with total C/N_o =	Phase slip = 0.001 with total C/N_o =
50 & None	Costas	26 dB-Hz	25.5 dB-Hz
50 & None	50	29 dB-Hz	23 dB-Hz
25 & None	50	26.5 dB-Hz	23 dB-Hz
50 & ½	50	24 dB-Hz	23 dB-Hz
33.3 & ½	50	22.5 dB-Hz	23 dB-Hz
25 & ½	**50**	**22 dB-Hz**	**23 dB-Hz**
25 & ½	25	24 dB-Hz	26 dB-Hz
25 & ½	75	24 dB-Hz	21 dB-Hz
33.3 & 1/3	50	22 dB-Hz	23 dB-Hz

Civil Signal Characteristics

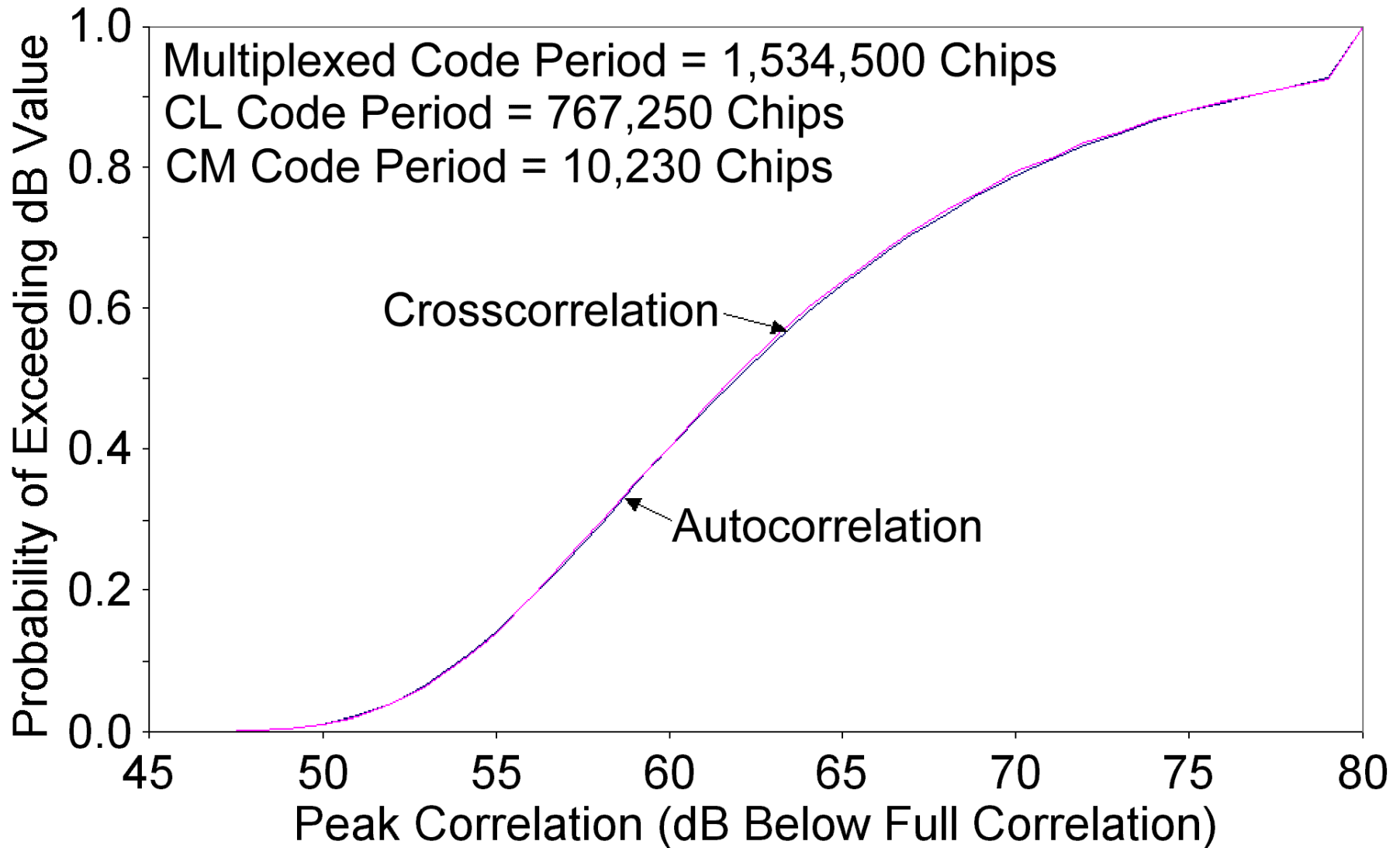| Civil Signal	Carrier Frequency (MHz)	Code Length (chips)	Code Clock (MHz)	Phases	Bit Rate (BPS)	Forward Error Correction
L1	1,575.42	1,023	1.023	Bi-Phase	50	No
L2	1,227.60	10,230 767,250	1.023	Bi-Phase	25	Yes
L5	1,176.45	10,230 10,230	10.23	Quad-Phase	50	Yes

Civil Signal Choices Functional Differences

Civil Signal	Fully Available	Ionospheric Error Ratio	Correlation Protection (dB)	**Relative** Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L1	Now	1.00	> 21	0.0 dB	0.0 dB
L2	~ 2011	1.65	> 45	+2.7 dB (FEC = 5 dB) (25 bps = 3 dB)	+0.7 dB (Phase locked tracking = 6 dB)
L5	~ 2015	1.79	> 30	+5.7 dB (FEC = 5 dB)	+6.7 dB

Correlation Performance

Multiplexed Code Period = 1,534,500 Chips
CL Code Period = 767,250 Chips
CM Code Period = 10,230 Chips

Crosscorrelation

Autocorrelation

Probability of Exceeding dB Value

Peak Correlation (dB Below Full Correlation)

L2C Advantages

- ◆ Best crosscorrelation protection (> 45 dB)
    - Aids navigation indoors and in forest areas
    - Provides headroom for increased SV power (GPS III ?)
    - Reduces impact of narrowband interference
- ◆ Better tracking and message thresholds than L1 C/A
- ◆ Available years sooner than L5
- ◆ <u>Lower</u> chip rate than L5
    - Saves power, minimizes thermal rise, better miniaturization
        - ➔ Battery powered use, e.g., cell phone and wristwatch products
    - More flexible RF/IF filter and signal processing options

L2C Bandwidth and Signal Processing Options

Max Accuracy

Lowest Cost

Max Protection